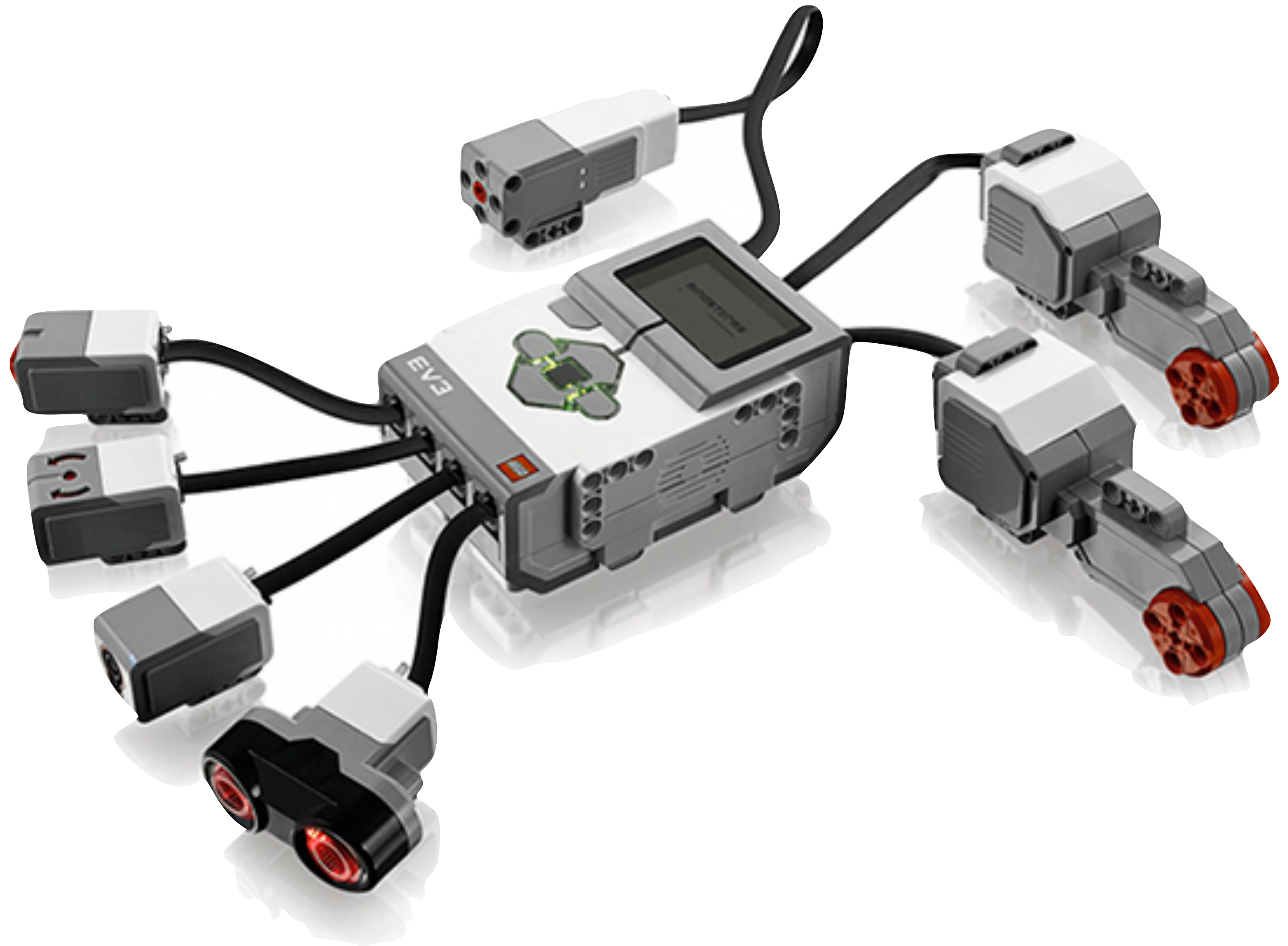

COMP329 Robotics and Autonomous Systems

Lecture 11: Locomotion

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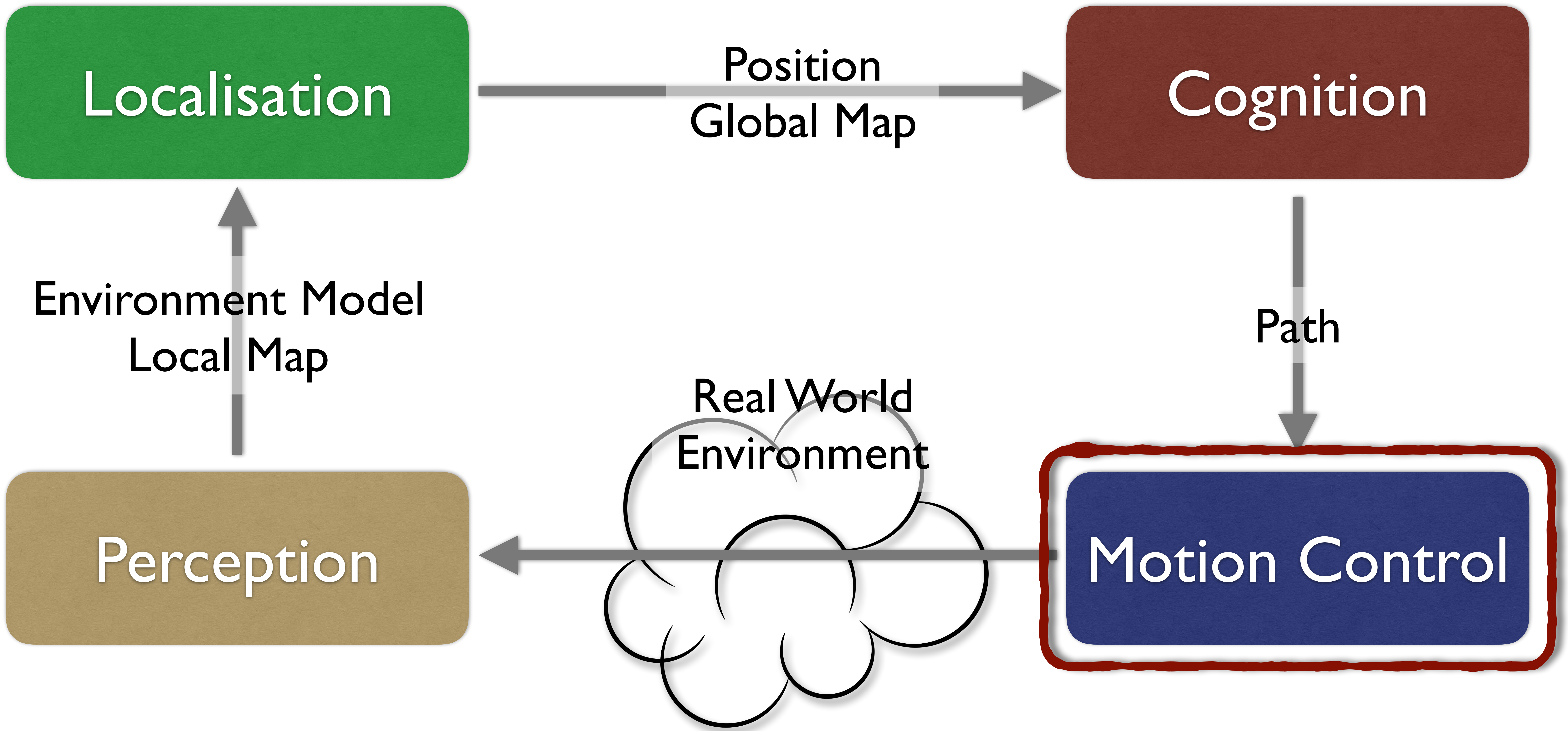
General control architecture

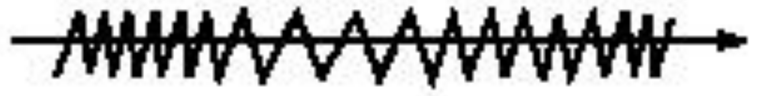
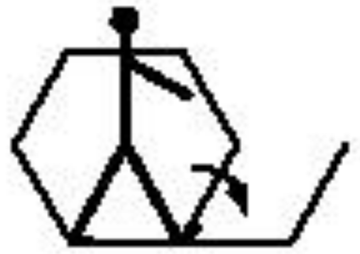


Original Source: M. Wooldridge, S.Parsons, D.Grossi - updated by Terry Payne, Autumn 2016 & 2017

Locomotion & Kinematics

- Two aspects to motion:
  - Locomotion
  - Kinematics
- ***Locomotion***:
  - What kinds of motion are possible?
  - What physical structures are there?
- *Kinematics*:
  - Mathematical model of motion.
  - Models make it possible to predict motion.

Locomotion in Action

Type of motion	Resistance to motion	Basic kinematics of motion
Flow in a Channel 	Hydrodynamic forces	Eddies 
Crawl 	Friction forces	 Longitudinal vibration
Sliding 	Friction forces	 Transverse vibration
Running 	Loss of kinetic energy	Oscillatory movement of a multi-link pendulum 
Jumping 	Loss of kinetic energy	Oscillatory movement of a multi-link pendulum 
Walking 	Gravitational forces	Rolling of a polygon (see figure 2.2) 

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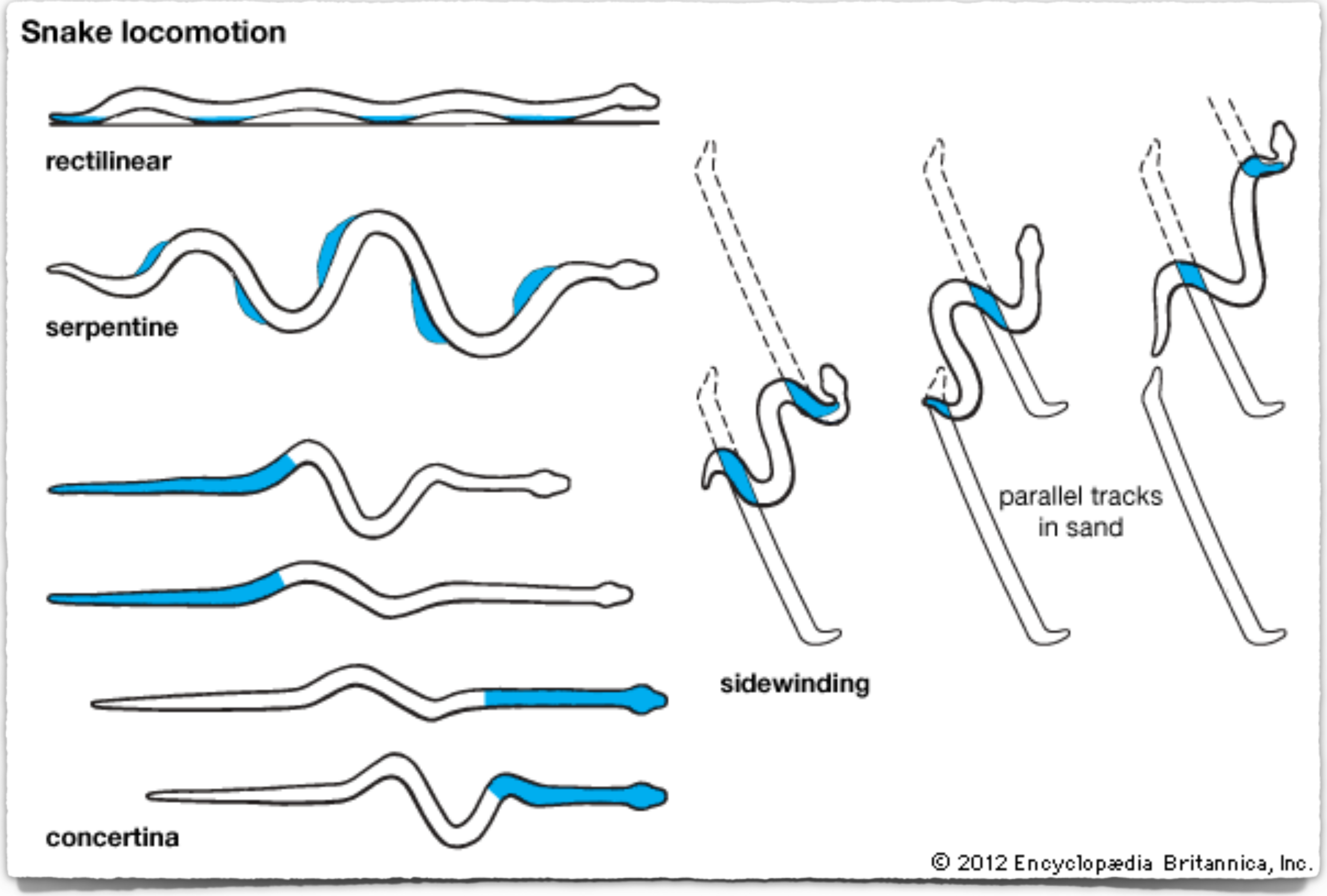
Sliding

- Snakes have four gaits!!!
  - Rectilinear
  - Lateral undulation
    - aka “serpentine”
    - (most common)
  - Concertina
  - Sidewinding



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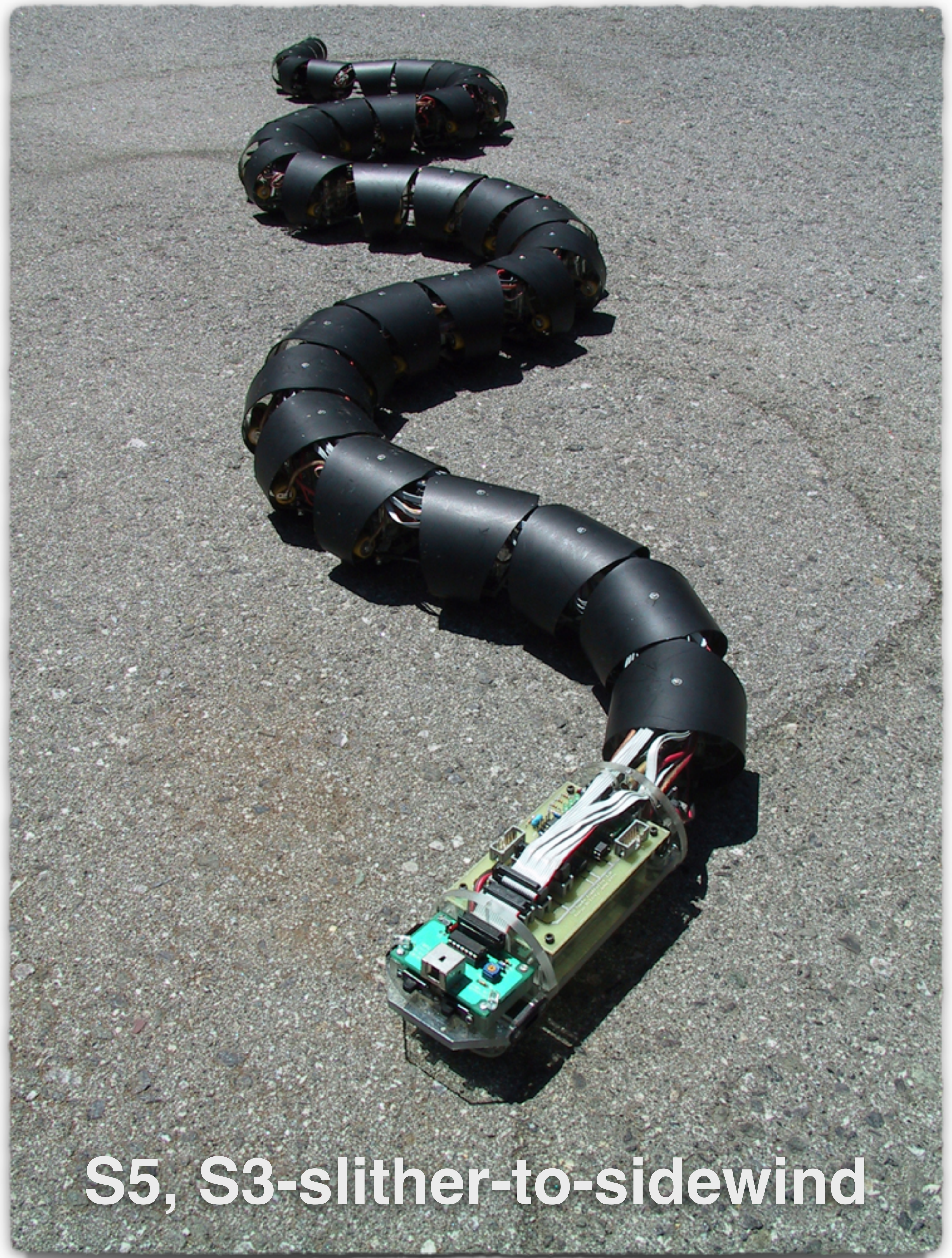

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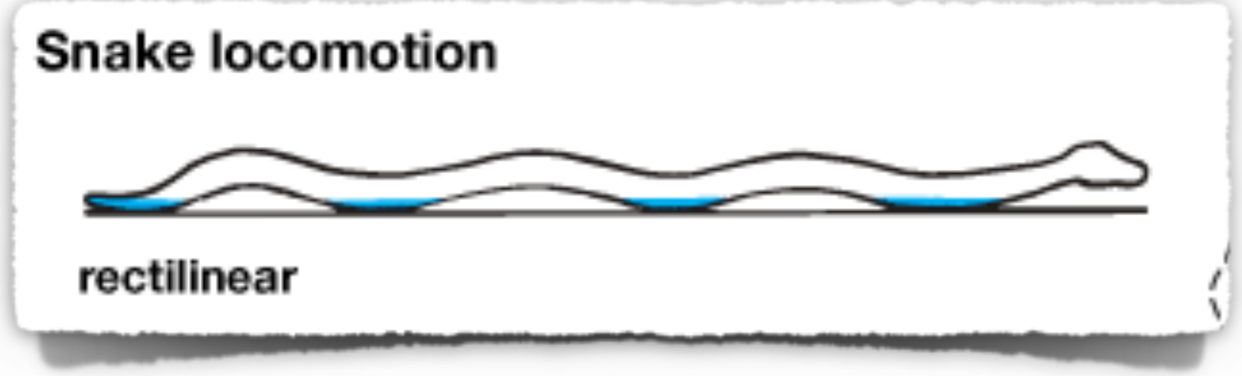
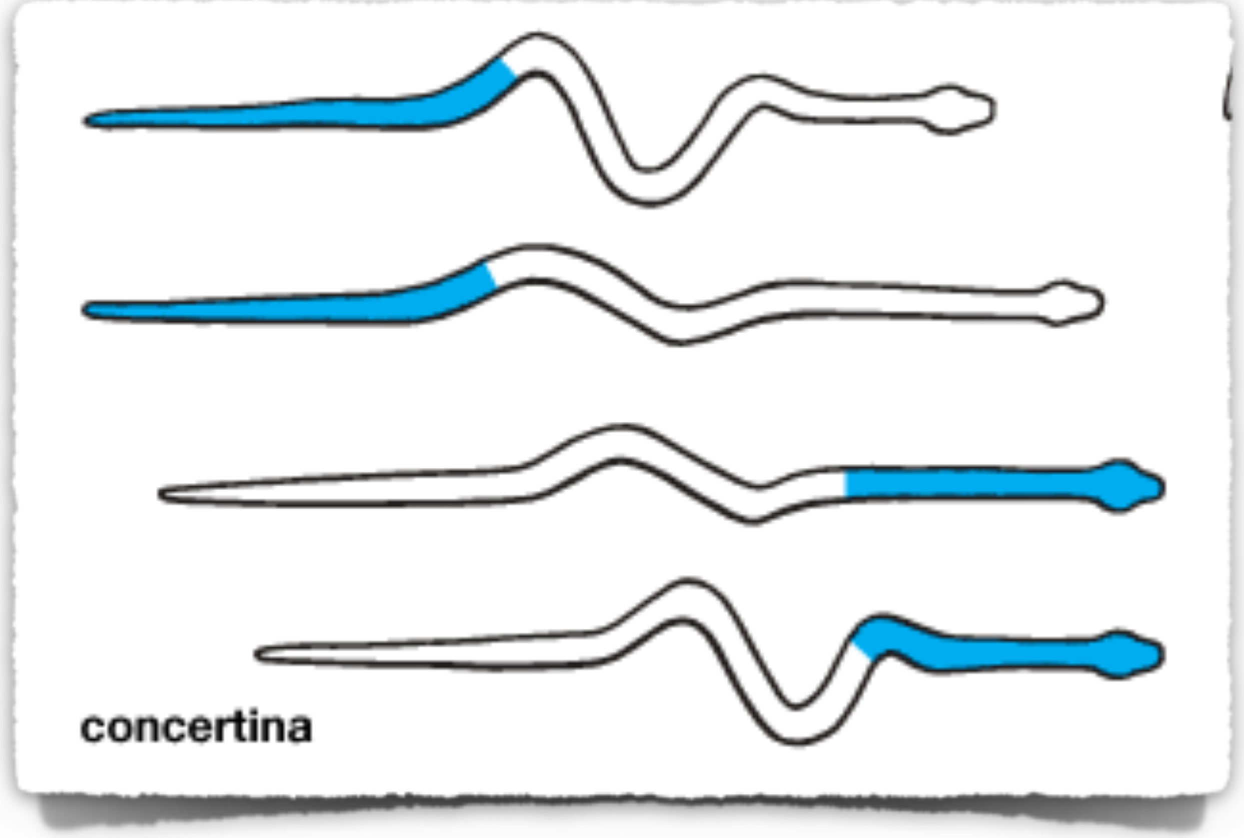
Example gaits

S5 Circles

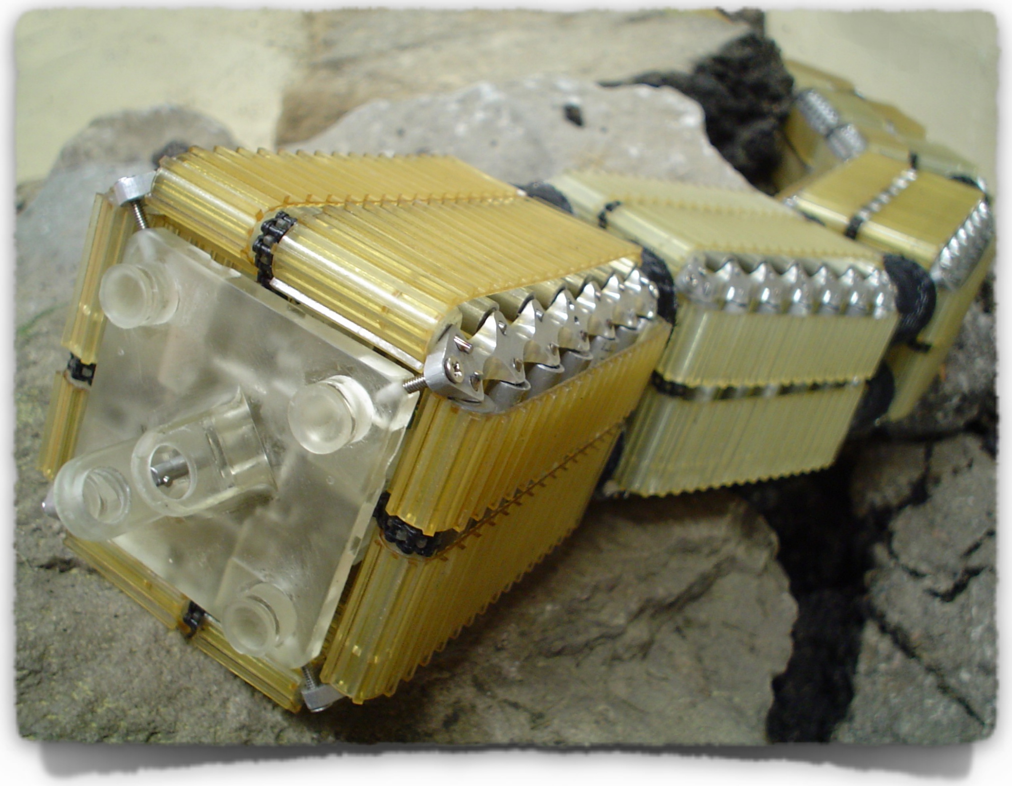
S3 Slither to Sidewind



Crawling



- Concertina and Rectilinear motion can be considered crawling.
  - Not directly implemented.
- The *Makro* (left) and *Omnitread* (right) robots crawl, but not exactly like real snakes do.



Characterisation of Locomotion

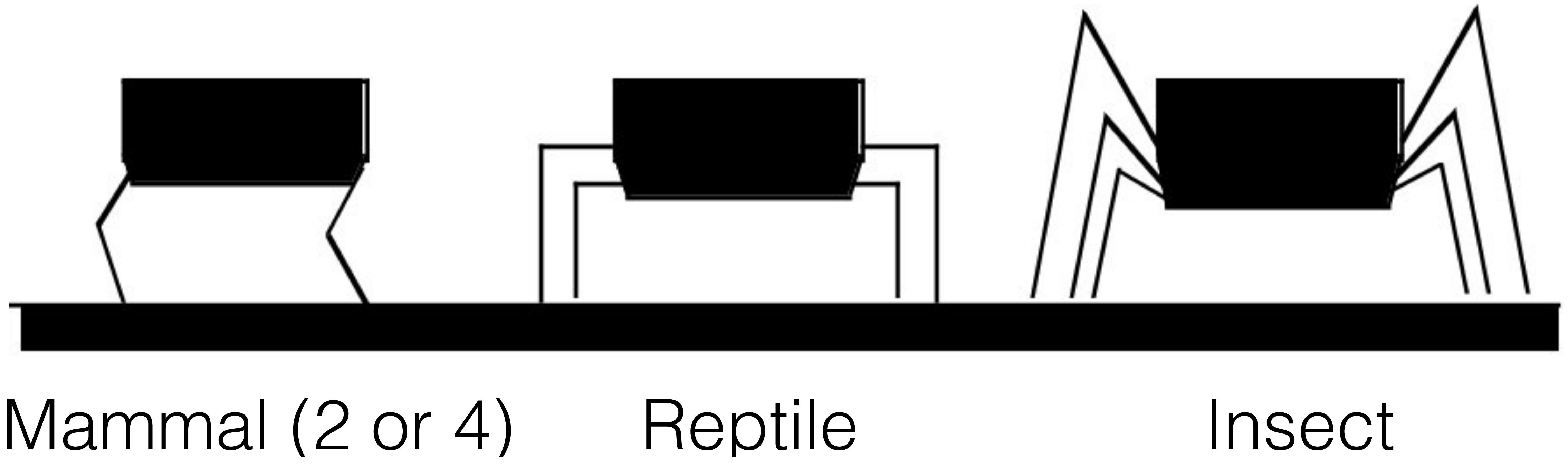
- **Locomotion**:
  - Physical interaction between the vehicle and its environment.
- Locomotion is concerned with **interaction** forces, and the **mechanisms** and **actuators** that generate them.
- The most important issues in locomotion are:
  - Stability
  - Characteristics of contact
  - Nature of environment

- ***Stability***
  - Number of contact points
  - Centre of gravity
  - Static/dynamic stabilisation
  - Inclination of terrain
- ***Characteristics of contact***
  - Contact point or contact area
  - Angle of contact
  - Friction
- ***Nature of environment***
  - Structure
  - Medium (water, air, soft or hard ground)

Original Source: M. Wooldridge, S.Parsons, D.Grossi - updated by Terry Payne, Autumn 2016 & 2017

Legged Motion

- The fewer legs the more complicated locomotion becomes
  - At least three legs are required for *static stability*
  - Babies have to learn for quite a while until they are able to stand or walk on their two legs.
- During walking some legs are lifted
- For *static walking* at least 6 legs are required
  - Alternate between tripod supports.
- Variety of leg joints/leg styles in nature:



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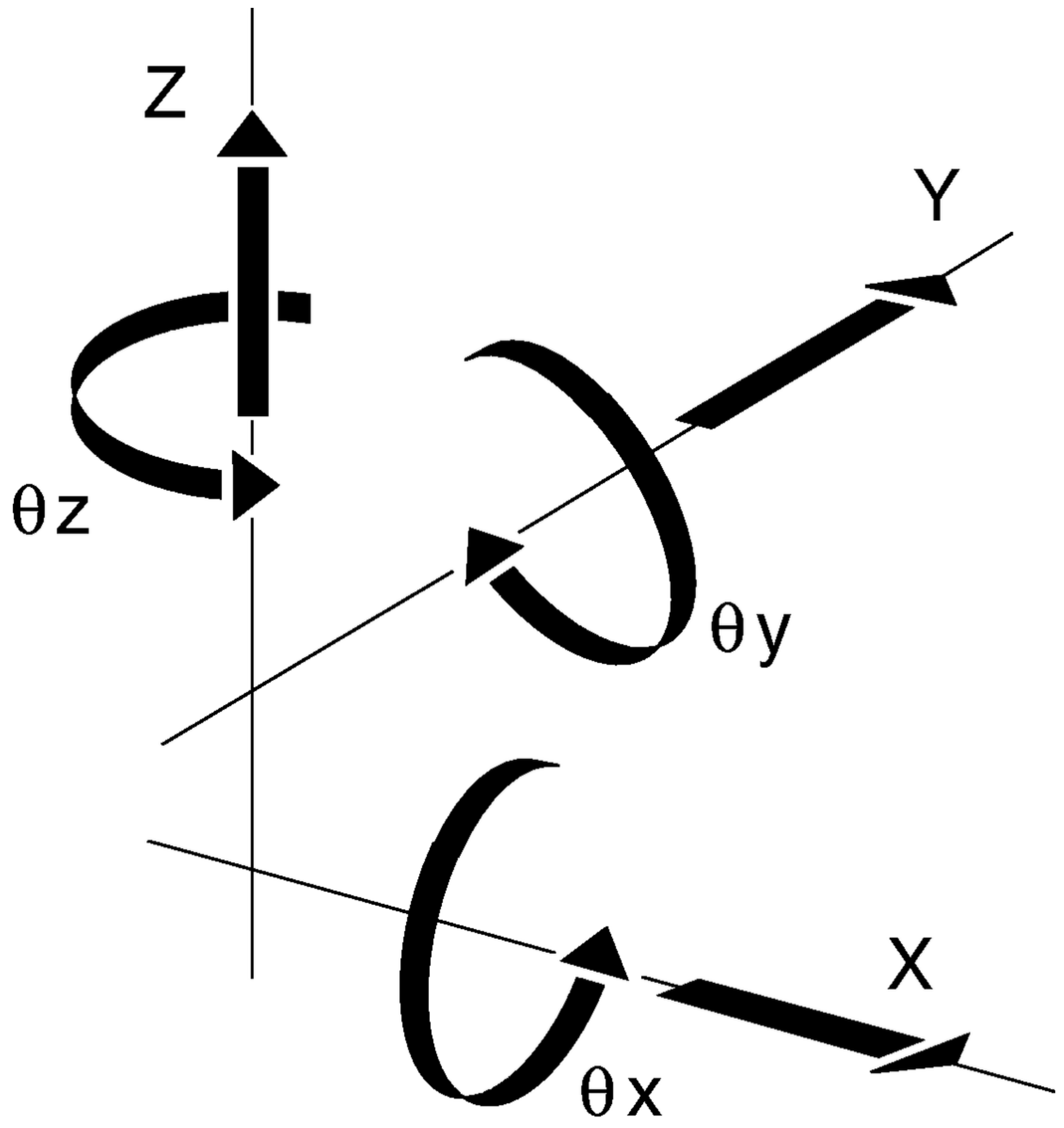
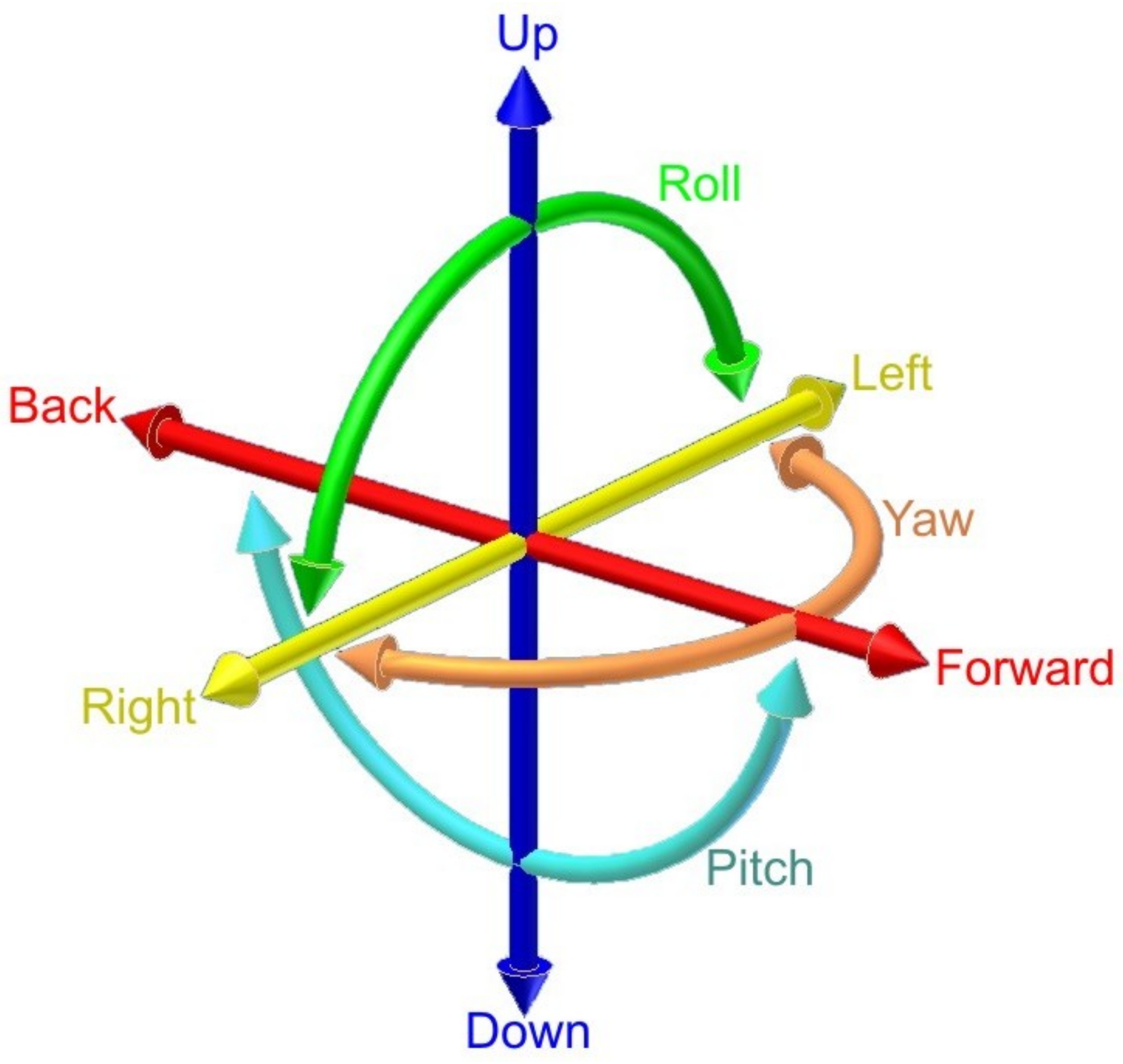
Degrees of Freedom

- Measurement of potential motion.
  - A three dimensional world allows a particle 6 degrees of freedom.





Original Source: M. Wooldridge, S.Parsons, D.Grossi - updated by Terry Payne, Autumn 2016 & 2017

Leg Joints

- The Robot structure restricts the *Degrees of Freedom* (DOF) of a point on the leg.
  - Typically interested in the foot.
- A minimum of two DOF is required to move a leg forward
  - A lift and a swing motion.
  - Sliding free motion in more than one direction not possible
- Three DOF for each leg in most cases
- Fourth DOF for the ankle joint
  - Might improve walking
  - However, additional joint (DOF) increases the complexity of the design and especially of the locomotion control.

Number of Gaits

- Gait is characterised as the sequence of lift and release events of the individual legs.
  - Depends on the number of *legs*

- The number of possible events N for a walking machine with k legs is:

$$N = (2k - 1)!$$

- For example, a biped walker (i.e. $k=2$ legs)
  - the number of possible events N is:

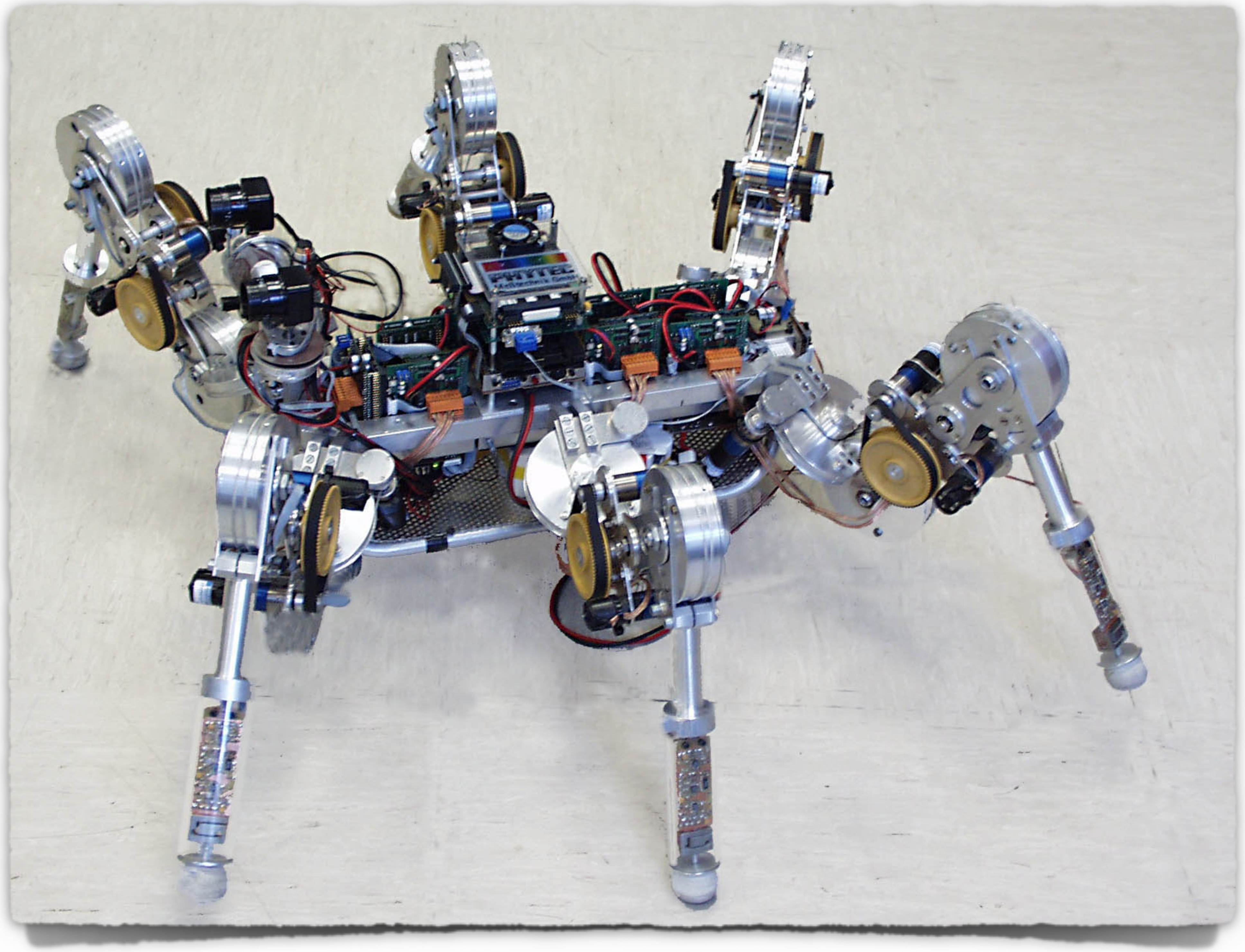
$$N = (4 - 1)! = 3! = 3 \times 2 \times 1 = 6$$

1. lift right leg
2. lift left leg
3. release right leg
4. release left leg
5. lift both legs together
6. release both legs together

Number of Gaits

- For a robot with 6 legs (hexapod)
  - The number of events N is ***much*** greater!

$$
\begin{aligned}
N &= ((2 * 6) - 1)! \\
&= 11! \\
&= 39,916,800
\end{aligned}
$$



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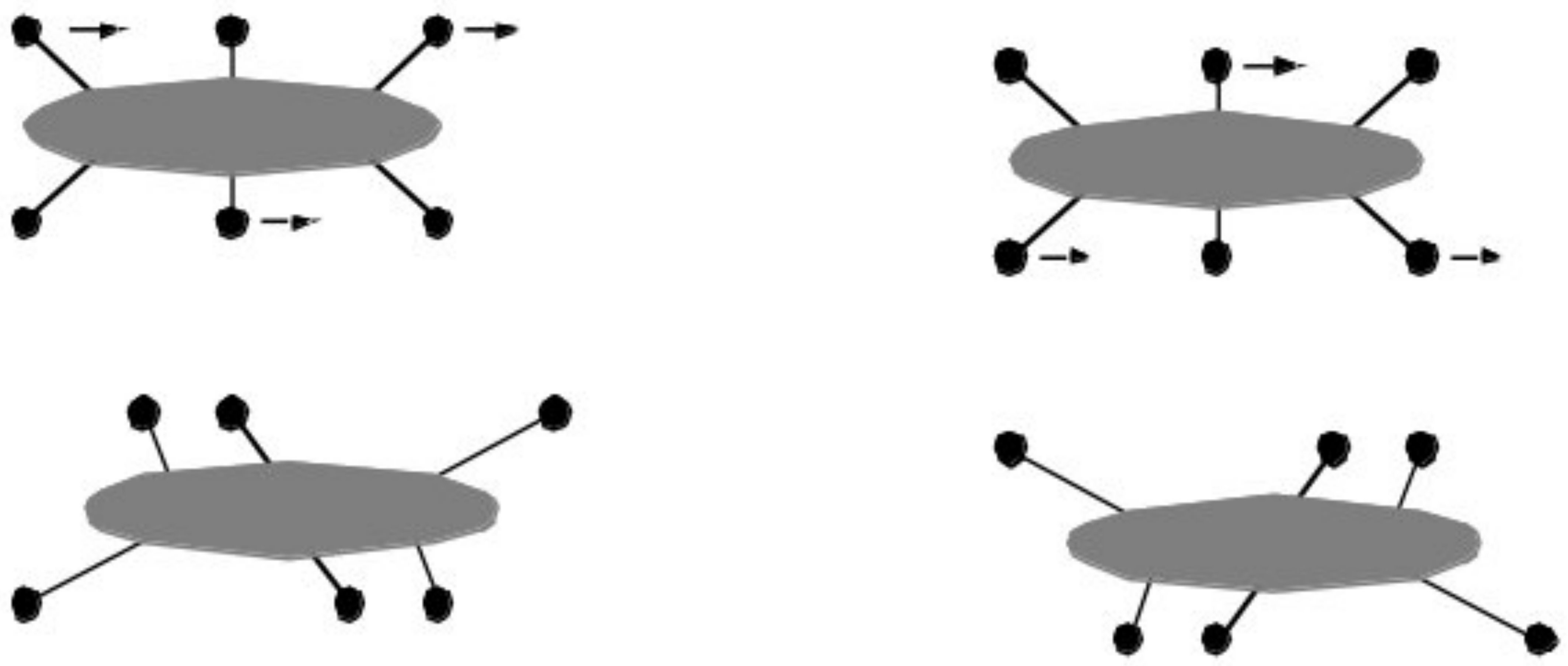
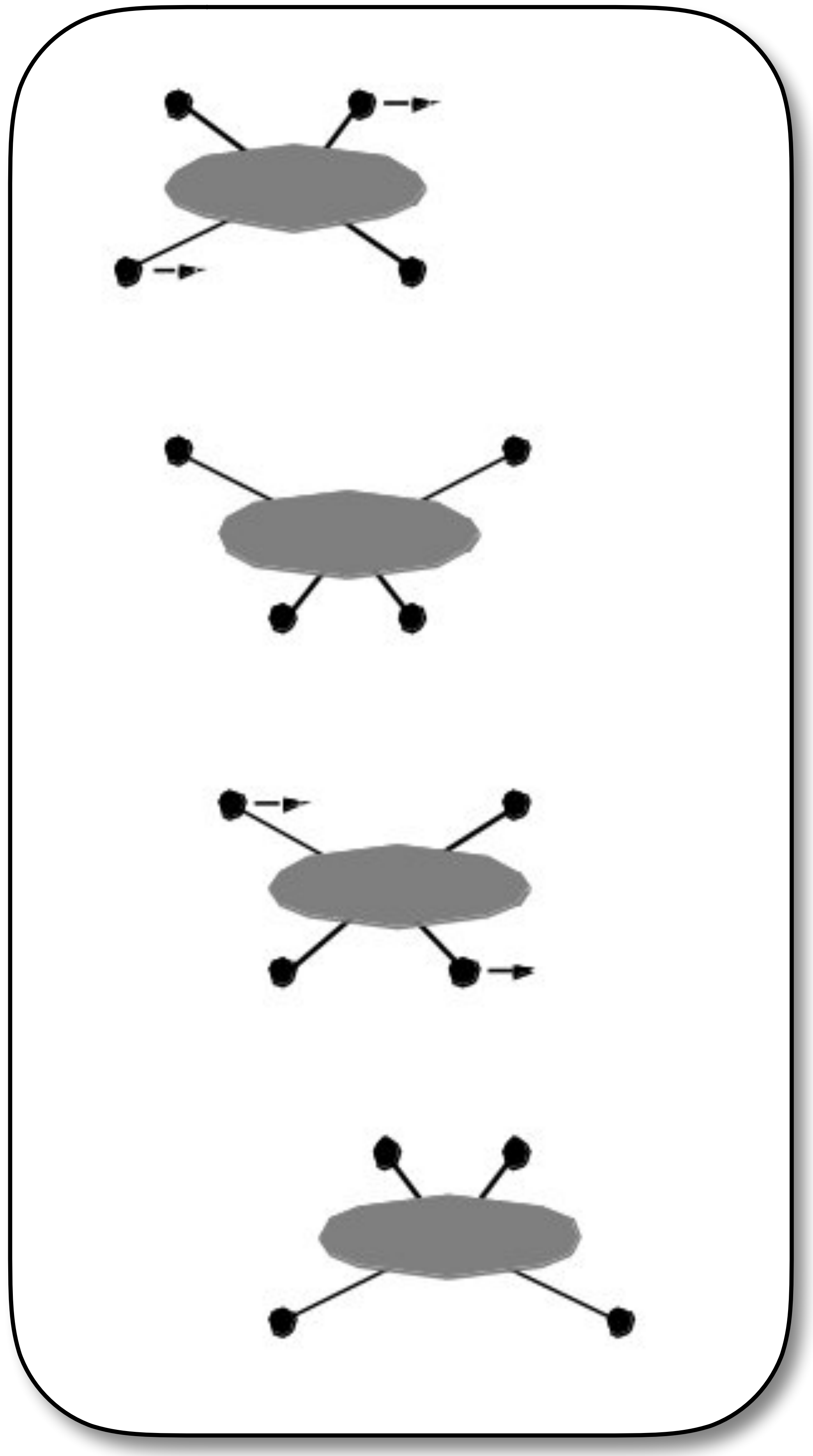
The obvious 6 legged Gait

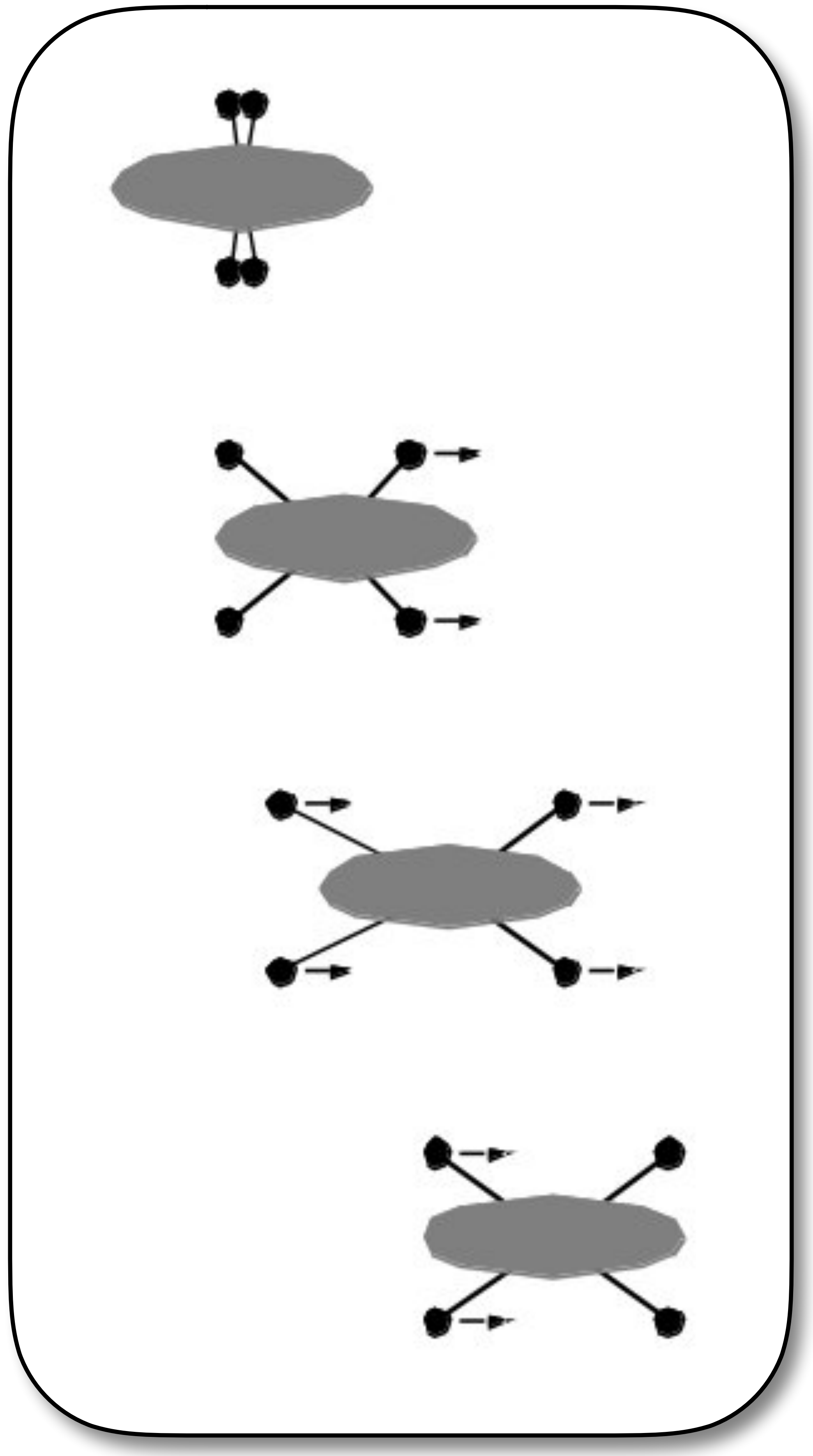
- Static stability - the robot is always stable.
    - *(six-legged-crawl)*



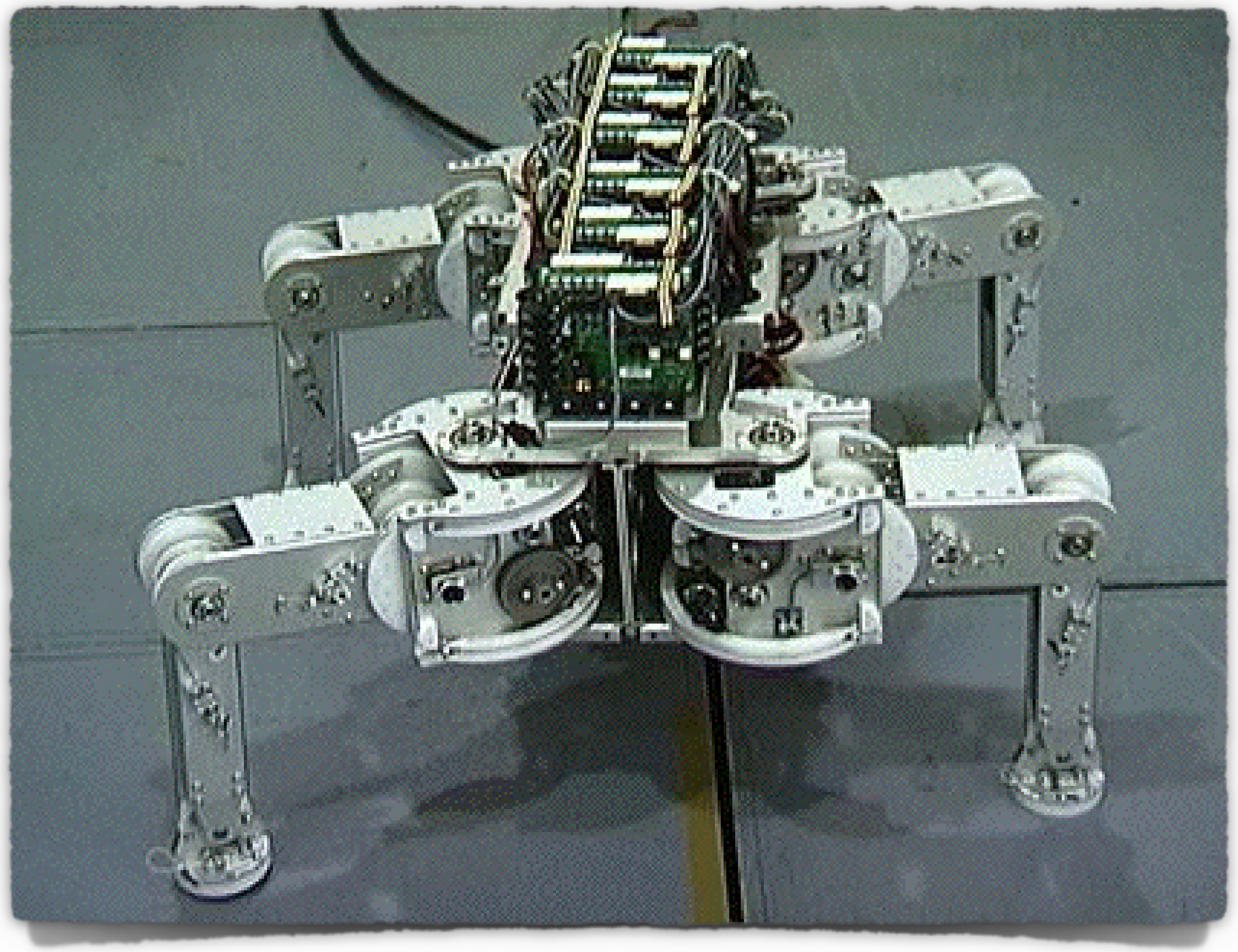
Four Legged Gaits



Changeover Walk



Gallop



The Titan VIII

This was one of a family of 9 robots, developed from 1976, to explore gaits

Original Source: M. Wooldridge, S.Parsons, D.Grossi - updated by Terry Payne, Autumn 2016 & 2017

Examples of 4 legged gaits

- The Big Dog and Little Dog robots emerged from DARPA funded research at MIT & Boston Dynamics

Learning Locomotion with LittleDog

http://www-clmc.usc.edu

Mrinal Kalakrishnan, Jonas Buchli, Peter Pastor, Michael Mistry, and Stefan Schaal

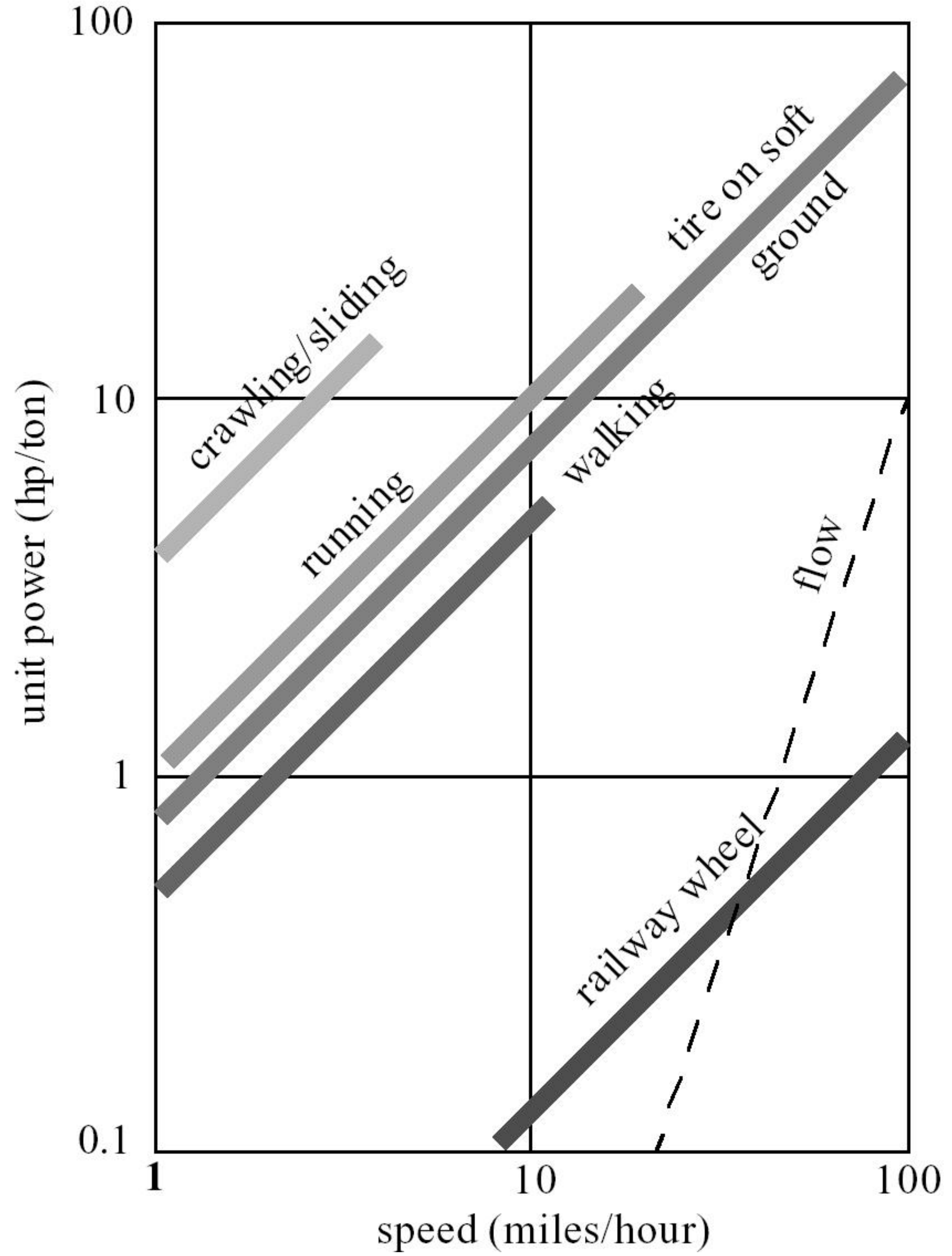
Humanoid Robots

- Two-legged gaits are difficult to achieve
  - human gait, for example is very unstable.

Original Source: M. Wooldridge, S.Parsons, D.Grossi - updated by Terry Payne, Autumn 2016 & 2017

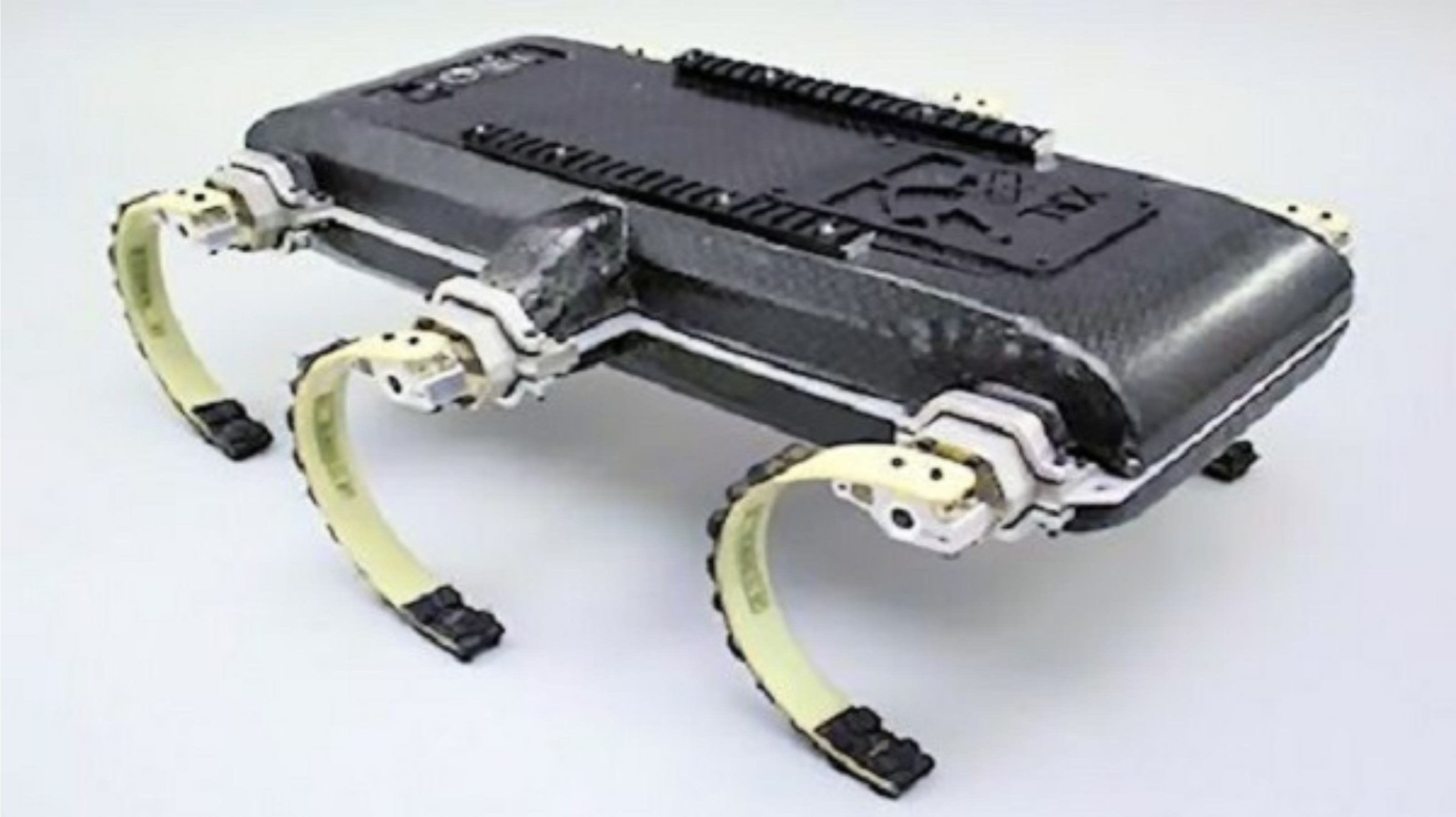
Walking or Rolling?

- Many factors determining the choice of locomotion:
  - Number of actuators
  - Structural complexity
  - Control expense
  - Energy efficient
  - Terrain (flat ground, soft ground, climbing..)



RHex

- Somewhere between rolling and walking
- Design facilitates several forms of motion



Original Source: M. Wooldridge, S.Parsons, D.Grossi - updated by Terry Payne, Autumn 2016 & 2017

Wheeled Robots

- Wheels are the most appropriate solution for many applications
  - Avoid the complexity of controlling legs
- Basic wheel layouts limited to easy terrain
  - Motivation for work on legged robots
- Much work on adapting wheeled robots to hard terrain.
- Three wheels are sufficient to guarantee stability
  - With more than three wheels a flexible suspension is required
- Selection of wheels depends on the application

Swedish Wheel

Four Basic Wheel Types

Standard wheel

Two degrees of freedom:

1. *rotation around the (motorised) wheel axle*; and

Spherical Wheel

AKA Ball! Omnidirectional, but suspension is technically not solved

Castor Wheel

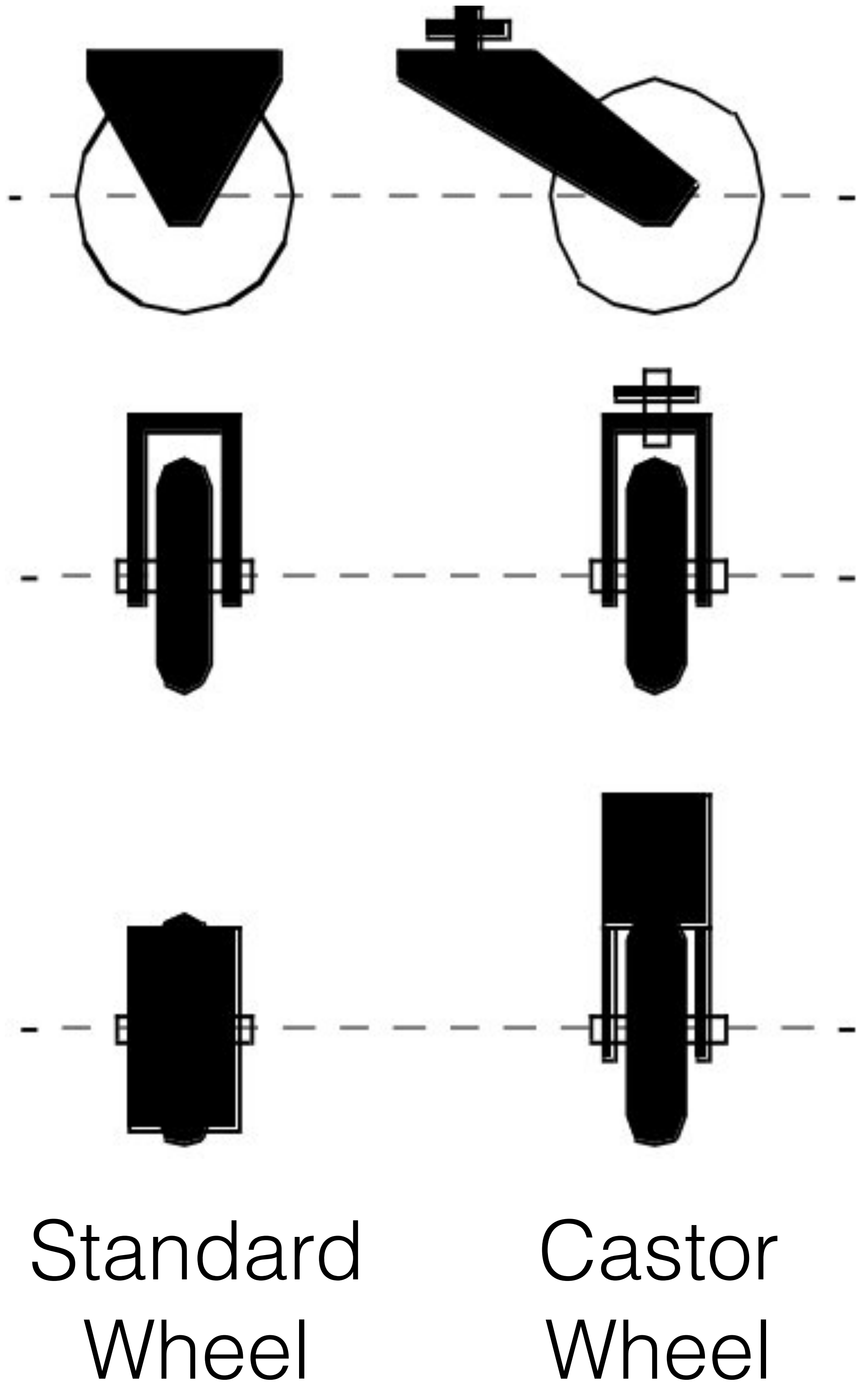
Three degrees of freedom :

1. *rotation around the wheel axle;*
2. *the contact point*; and
3. *rotation around the castor axle*

Swedish Wheel

Three degrees of freedom:

1. *rotation around the (motorised) wheel axle;*
2. *around the rollers (45*^{o}*)*; and
3. *the contact point;*



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Invented in 1973 by Bengt Ilon, who was working for the Swedish company Mecanum AB.

Also called a Mecanum or Ilon wheel

smARTLab@work

RoboCup World championships 2014
João Pessoa, Brazil

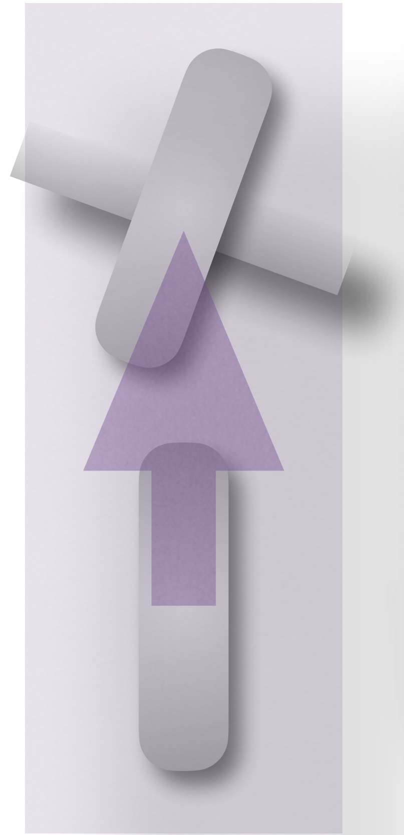
Characteristics of Wheeled Vehicles

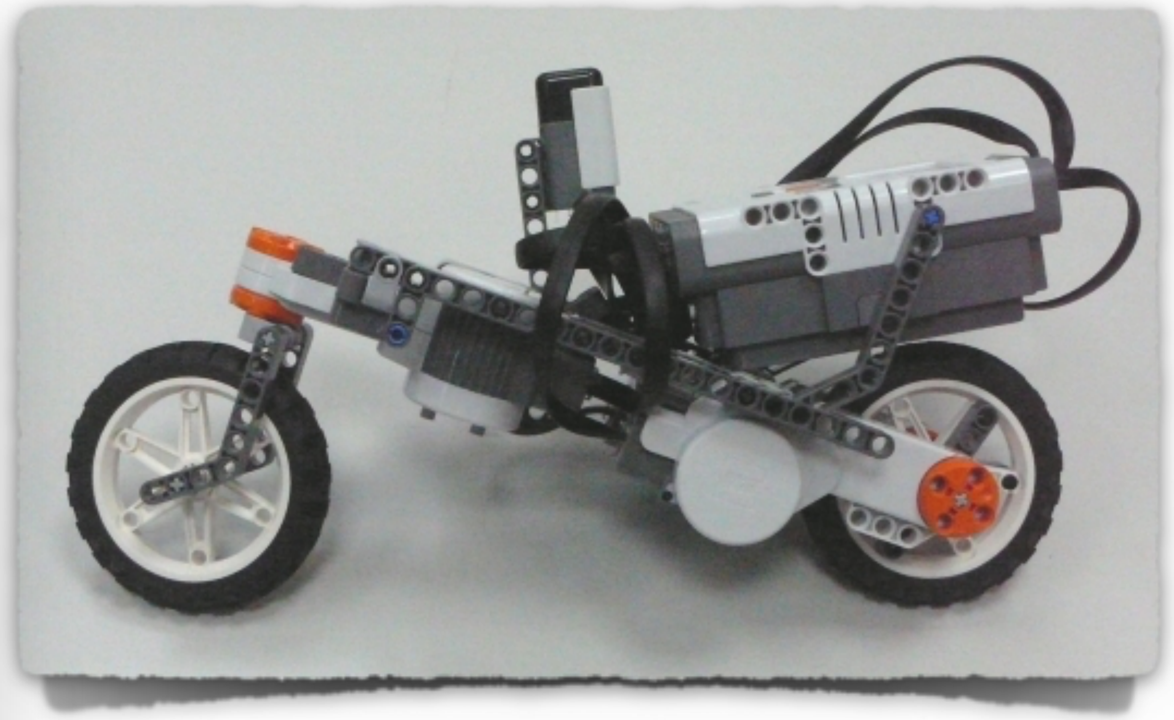
- Stability of a vehicle is be guaranteed with 3 wheels.
  - Centre of gravity is within the triangle with is formed by the ground contact point of the wheels.
- Stability is improved by 4 and more wheels.
  - However, such arrangements with more than three contact points are *hyperstatic* and require a flexible suspension system.
- Bigger wheels allow robot to overcome higher obstacles.
  - But they require higher torque or reductions in the gear box.
- Most wheel arrangements are non-holonomic (see later)
  - Require high control effort
- Combining actuation and steering on one wheel makes the design complex and adds additional errors for odometry.

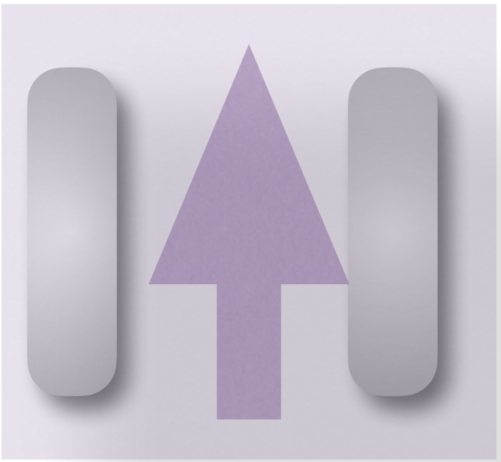
Original Source: M. Wooldridge, S.Parsons, D.Grossi - updated by Terry Payne, Autumn 2016 & 2017

Two Wheels

- Two main approaches:
  - ***Steering wheel*** at front, drive wheel at back.
    - Stability issues, not that common
  - ***Differential drive***.
    - Turning achieved by varying the individual velocity / speed of each wheel
    - Centre of mass above or below axle.







Segway RMP

mass above centre of gravity

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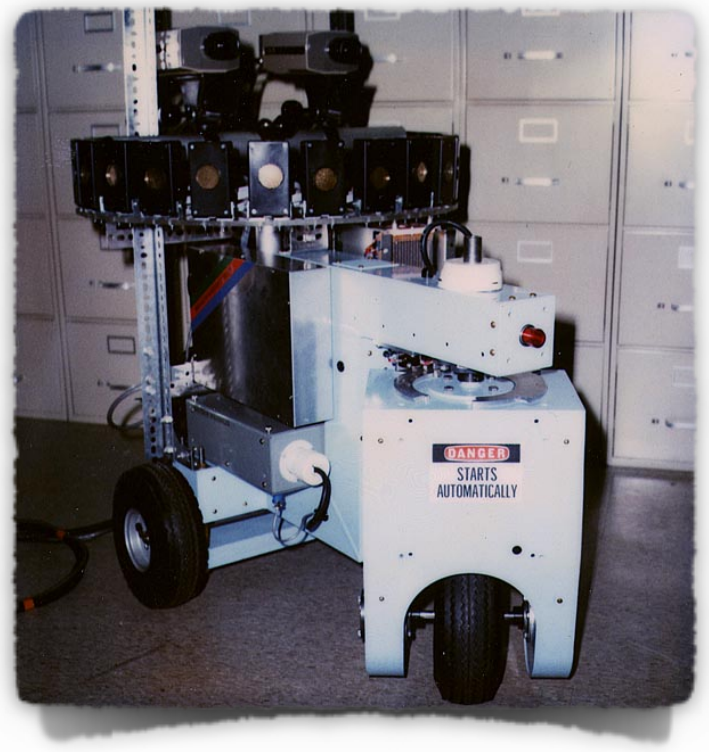
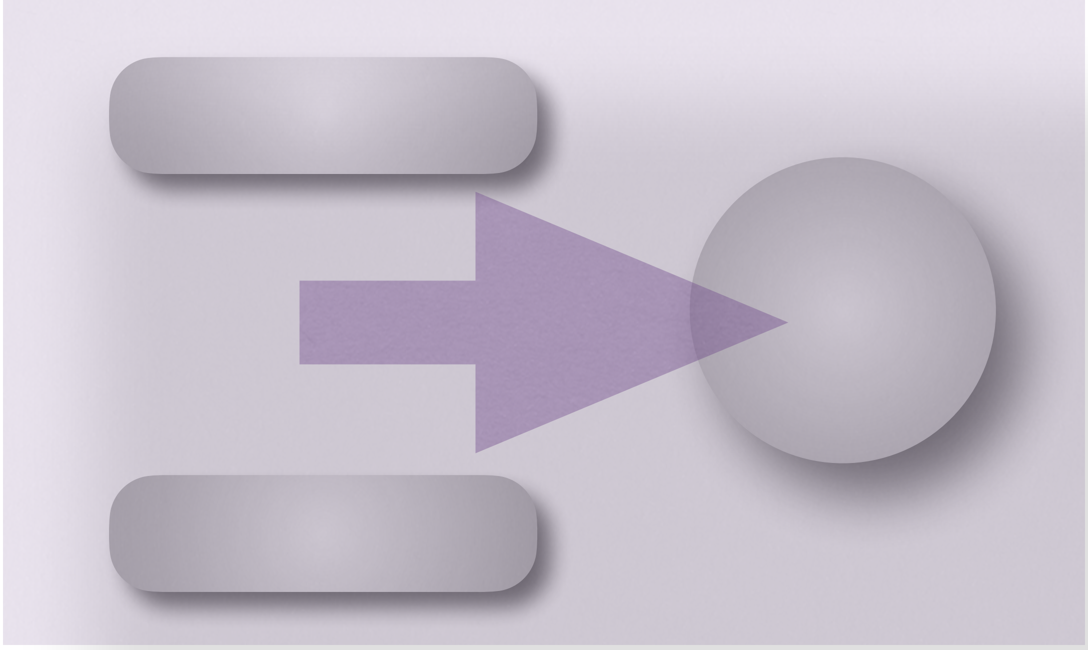
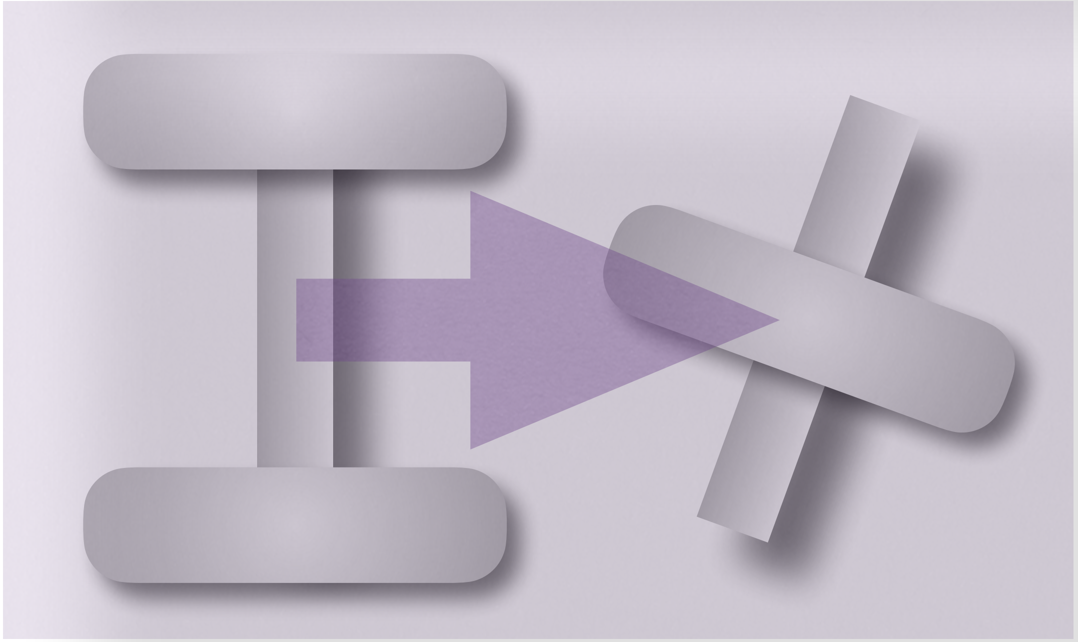


Three Wheels

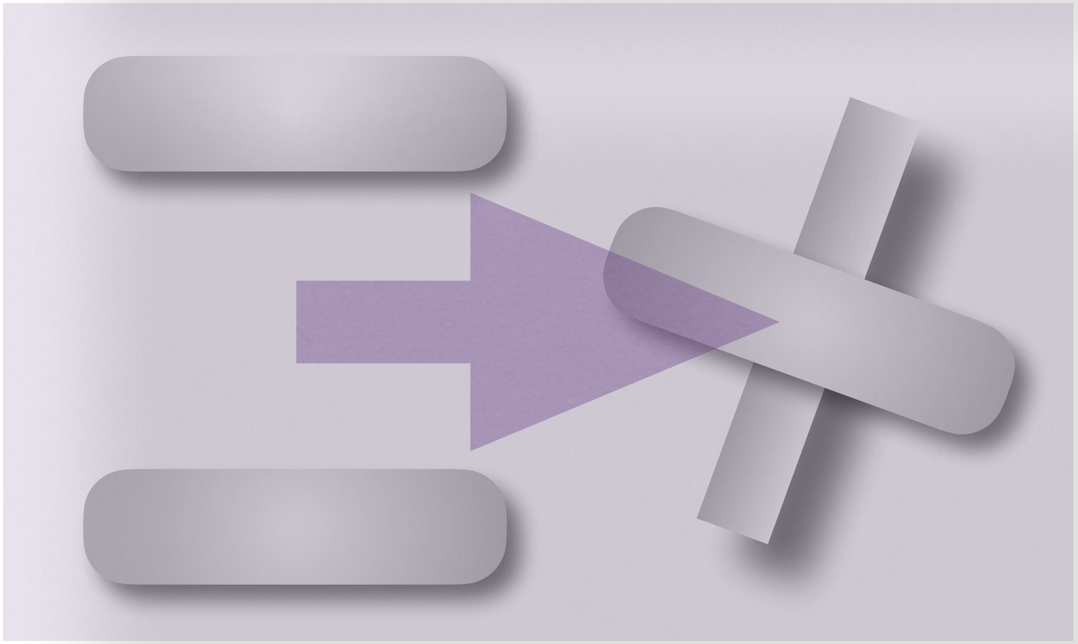
- Differential drive plus caster or omnidirectional wheel.
  - Highly manoeuvrable, but limited to moving forwards/backwards and rotating



- Connected drive wheels at rear, steered wheel at front.



- Two free wheels in rear, steered drive wheel in front.



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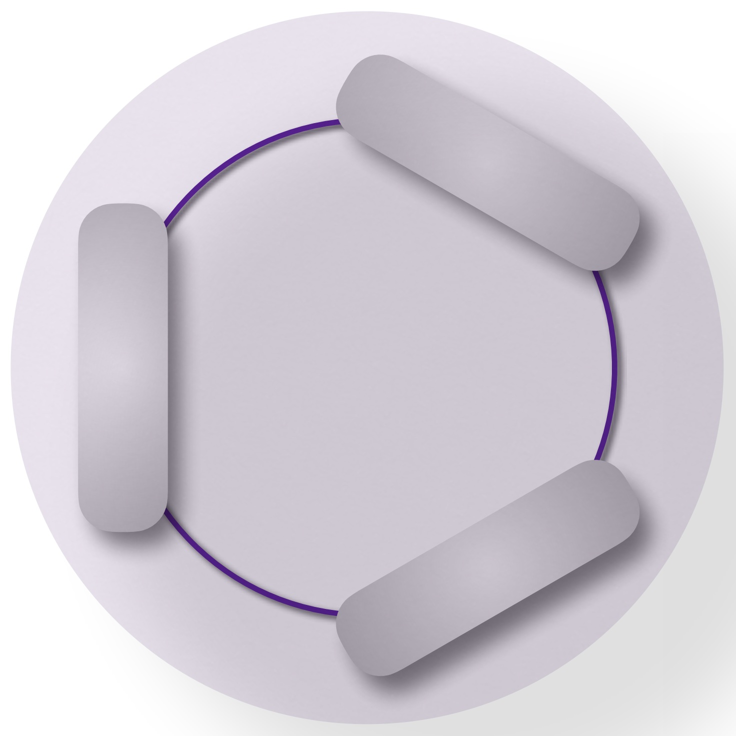
Differential + Caster

- Highly manoeuvrable, but limited to moving forwards/ backwards and rotating

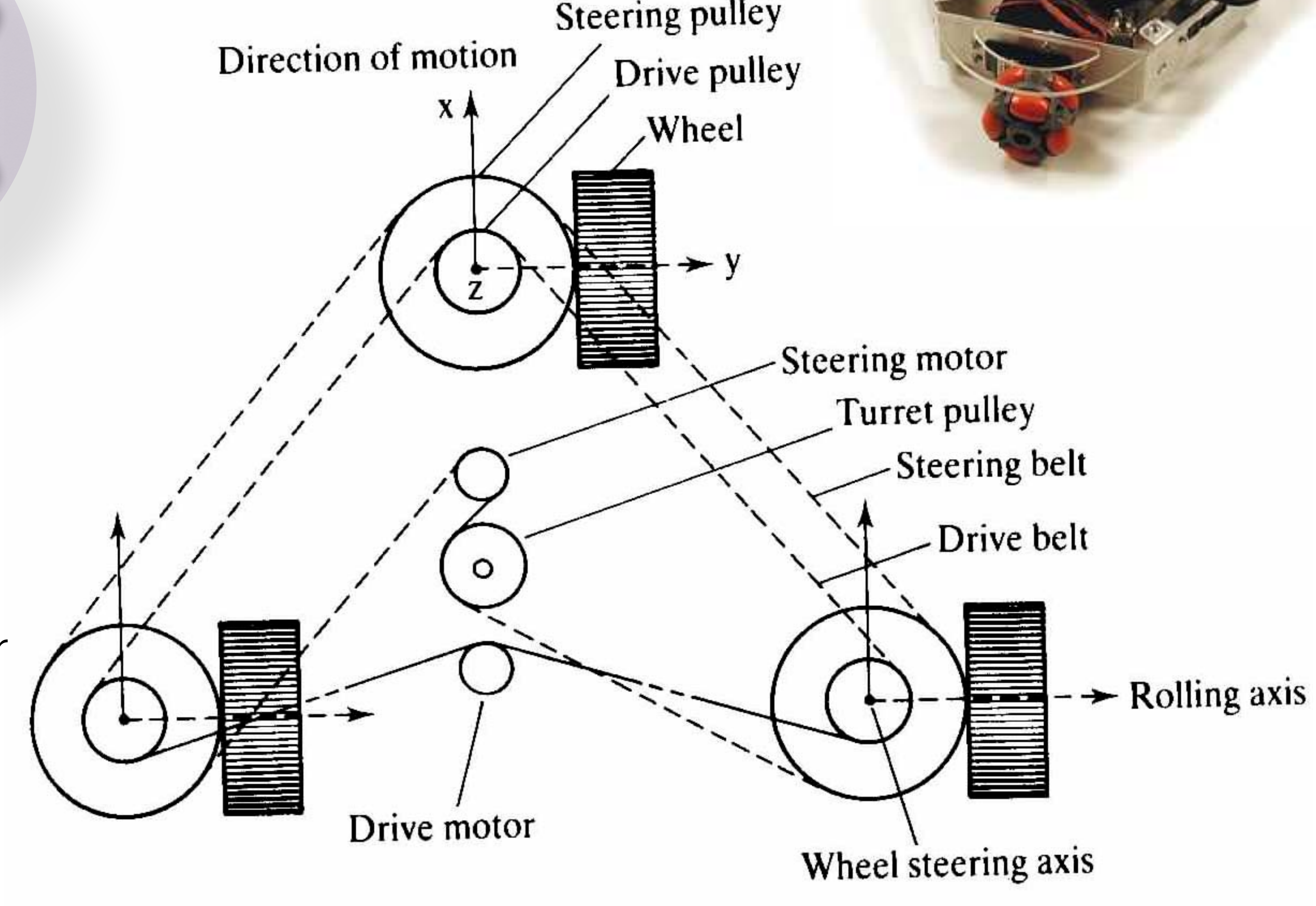
Pioneer 3dx

TurtleBot

Other three wheel drives



- ***Omnidirectional***
  - Three drive wheels.
  - Swedish or spherical.



- ***Synchro drive***
  - Three drive wheels.
    - All wheels are actuated synchronously by one motor
      - Defines the speed of the vehicle
    - All wheels steered synchronously by a 2^{nd} motor
      - Sets the heading of the vehicle
  - The orientation in space of the robot frame will always remain the same

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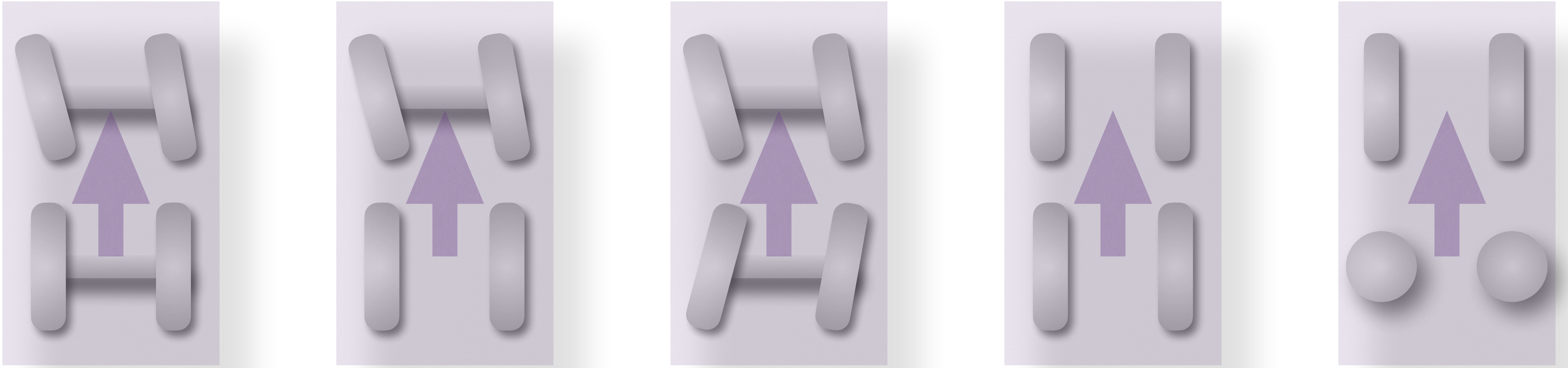
Four wheels

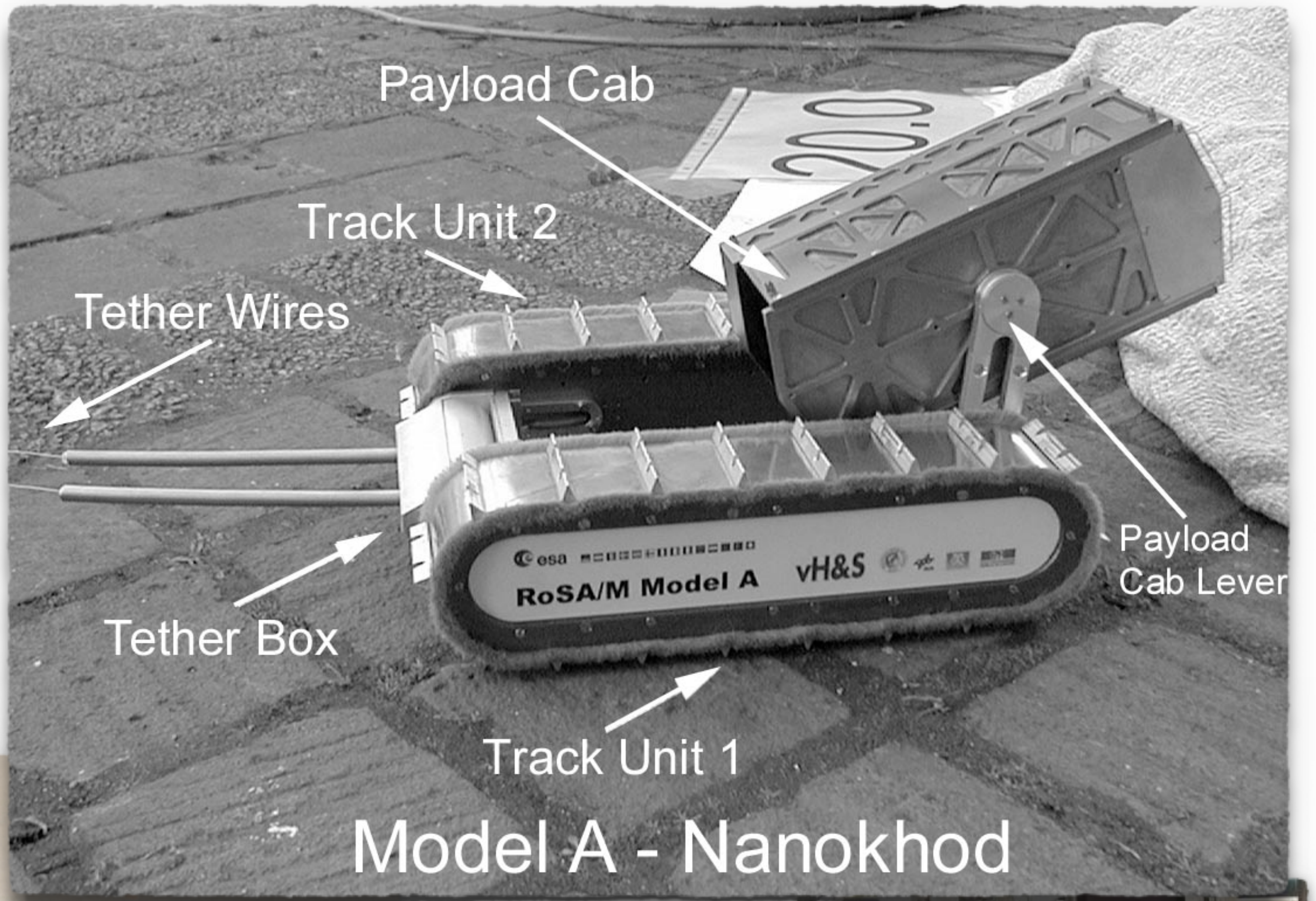


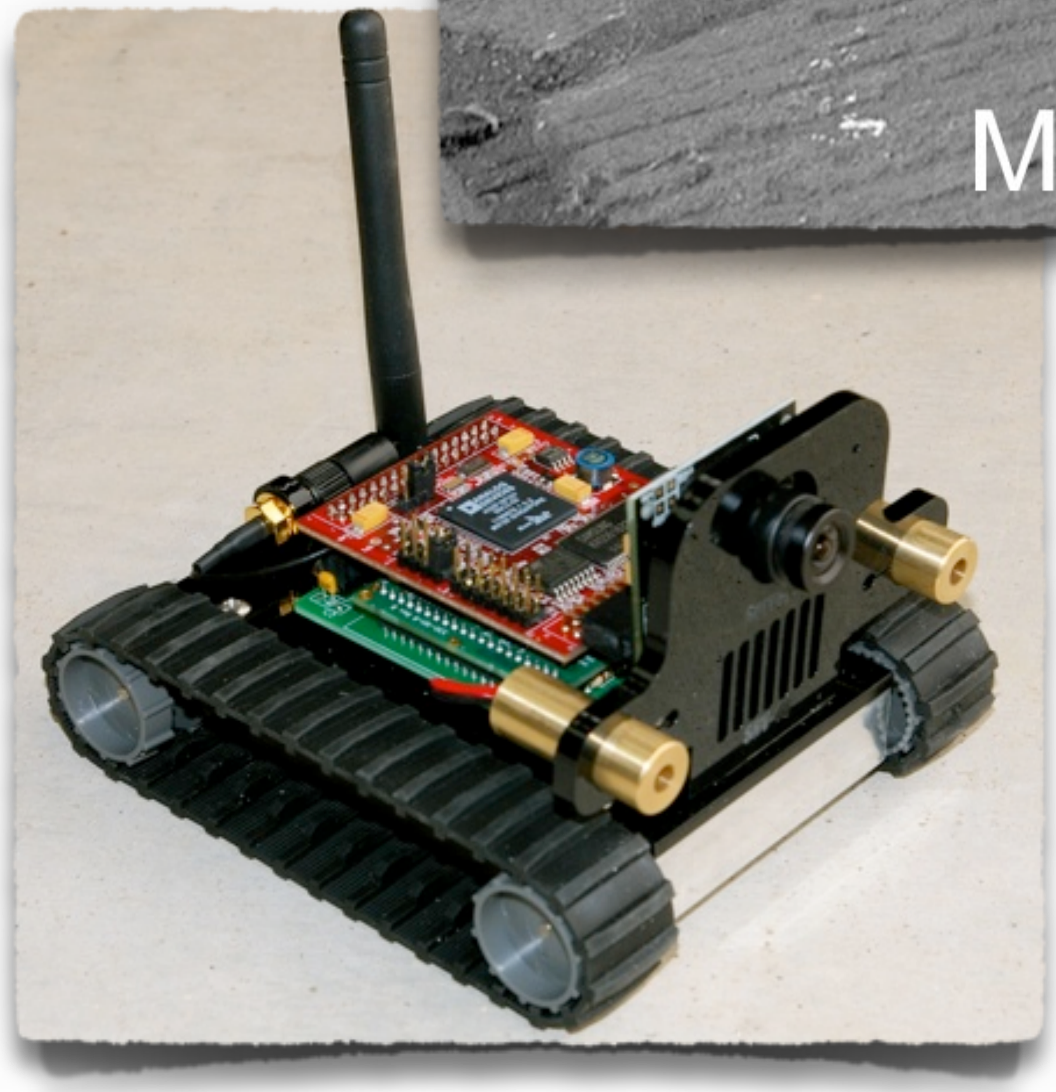
- Various combinations of steered, driven wheels and omnidirectional wheels.
  - Highly manoeuvrable, hard to control.

Original Source: M. Wooldridge, S.Parsons, D.Grossi - updated by Terry Payne, Autumn 2016 & 2017

Slip/skid steering / Tracked Robots

- Large contact area means good traction.
  - Use slip/skid steering.
- Also used on ATV versions of differential drive platforms.
  - Causes problems with odometry.





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Aerial & Fish Robots

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Summary

- This lecture looked at locomotion.
  - It discussed many of the kinds of motion that robots use, giving examples.
  - When building a robot, it is useful to know how it will move.
    - This helps in developing the control program.
    - Less trial and error.

- Next time we will move on to look at the other part of motion, kinematics.
  - In this we move from purely qualitative descriptions of motion to more mathematical descriptions.
  - These have the great advantage of allowing us to compute useful things about motion.

Original Source: M. Wooldridge, S.Parsons, D.Grossi - updated by Terry Payne, Autumn 2016 & 2017